BACK GROUND OF INVENTION

The present invention relates to a Crest Factor reduction and amplitude pre-distortion circuit to boost the out put power of a multi-carrier wireless RF amplifier. The Crest Factor reduction and amplitude pre-distortion circuit main input could be baseband, intermediate frequency (IF), or RF signal, the feedback signal from the amplifier is at the operating frequency and its output is the Crest Factor reduced RF signal as a new input to the amplifier. In any wireless communication system one of the critical components is the power amplifier. This component has a major contribution in cost, power consumption, and size of the system. The main reason is the requirement of wireless radio communication system for linear amplifiers. The higher the linearity, the higher the power consumption, cost and size. In order to minimize the cost, size and power consumption there is a need for techniques that overcome this problem. This invention conquers these challenges by using a simple and accurate Crest Factor reduction and amplitude pre-distortion module used at the input to the amplifier.

SUMMARY OF INVENTION

According to the invention, a low-cost RF Crest Factor reduction and amplitude pre-distortion circuit, for use with multi-carrier RF amplifier, uses a plurality of simple and accurate circuits in conjunction with intelligent signal processing to improve power handling of the multi-carrier amplifier. By intelligent, it is meant that the Crest Factor reduction and amplitude pre-distortion module has features of removing the unwanted signals after applying the Crest Factor reduction and amplitude pre-distortion function. It also has features of adaptability to the environment, such as ability to consider the changes due to environmental changed and aging. The Crest Factor reduction and amplitude pre-distortion module uses the amplifier input which could be a baseband, an IF or RF signal as its input and conditions the input before applying to the multi-carrier amplifier. The conditioning or Crest Factor reduction and amplitude pre-distortion helps

to boost the power handling of the amplifier or acts more linearly. The inputs to the Crest Factor reduction and amplitude pre-distortion should be within a limit that can be handled by the Crest Factor reduction and amplitude pre-distortion module.

In a particular embodiment, the Crest Factor reduction and amplitude pre-distortion unit comprises a multi-carrier transmitter, an envelop detector, a multi-carrier broadband receiver, a signal processing, and a clock generator. The receiver converts the baseband, IF, or RF signal to digital baseband and the transmitter converts the digital baseband signal to RF. The envelop detector takes the feedback from the amplifier and detects the envelop of the feedback signal. The signal processor performs the signal conditioning as well as performs the initial calibration, and transmitter and receiver control.

The invention will be better understood by reference to the following detailed description in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an overall block diagram of the a amplifier with a booster using Crest Factor reduction and amplitude pre-distortion

FIG. 2 is the block diagram of the Crest Factor reduction and amplitude pre-distortion module

FIG. 3 is the block diagram of the digital processing unit of Crest Factor reduction and amplitude pre-distortion module

FIG. 4 is the block diagram of the digital signal processing block performing the Crest Factor reduction and amplitude pre-distortion

FIG. 5 is the detail block diagram of Crest Factor reduction

FIG. 6 is the block diagram of the look up table adaptation algorithm

FIG. 7 is the block diagram of the gain adjustment algorithm

FIG. 8 is the block diagram of the summing correlator used in both gain and phase adjustment algorithms.

FIG. 9 is the block diagram delay adjustment algorithm

FIG. 10 is the block diagram of sample selection

DESCRIPTION OF THE SPECIFIC EMBODIMENTS

In a first preferred embodiment the Crest Factor reduction and amplitude pre-distortion circuit monitors the signal strength of the multi-carrier input signal channels using the input receiver and finds the frequency and channel number of the input signals. In a second preferred embodiment of the invention, the Crest Factor reduction and amplitude pre-distortion circuit uses sub-harmonic sampling to convert multi-carrier RF or IF signals to digital baseband signal. In a third preferred embodiment the envelop of the feedback signal from output of the amplifier is converted to digital feedback envelop signal. In a fourth preferred embodiment the input signal is conditioned or Crest Factor reduced using the multi-carrier baseband signal. In a fifth preferred embodiment the digital baseband signal is further down converted to produce the individual carrier baseband signal. In a sixth preferred embodiment the multi-carrier signal is amplitude clipped or limited either in analog or digital domain. In a seventh preferred embodiment the individual baseband signals are individually filtered and up converted to reconstruct the multi-carrier digital baseband signal. In a eighth preferred embodiment the Crest factor reduced main signal is pre-distort using a look up table. In a ninth preferred embodiment the digitized feedback envelop signal from the output of the amplifier and the Crest Factor reduced signals are used to produce the amplitude pre-distortion look up table. In a tenth preferred embodiment the digitized feedback envelop signal from the output of the amplifier and the Crest Factor reduced main baseband signals are used to adjust the gain and the timing of the two inputs to the amplitude look up table algorithm.

Referring to Figure 1, a Crest Factor reduction and amplitude pre-distortion circuit diagram is illustrated. The systems receive its inputs from wireless transmitter 100. The output of the Crest Factor reduction and amplitude pre-distortion circuit 200 is applied to the input of the amplifier block 300. The Crest Factor reduction and amplitude pre-distortion circuit performs the following functions:

1. Finds the frequencies and channel numbers of the multi-carrier wireless transmitter output 100.

2. Reduce the Crest Factor of the input signal 100 before applying to the amplifier.

3. Pre-distort the amplitude of the Crest Factor reduced signal 100 before applying to the amplifier.

4. Use the Crest Factor reduced signal and the digitized feedback envelop signal from the output of the amplifier to produce the amplitude pre-distortion look up table.

5. Adaptively adjust the gain in the signal paths to keep the total gain from input to output of the Crest Factor reduction and amplitude pre-distortion zero.

6. Adaptively adjust the gain in the signal paths from main multi-carrier receiver and feedback envelop signal to an equal and optimal level for further processing.

7. Adaptively adjust the delay in the multi-carrier receiver signal path, until the main and feedback signals are aligned in time/phase. This is measured by cross-correlating between the two signals.

8. Select the best sample value by changing the decimation filter coefficients. This allows the delay to be adjusted to a small fraction of input signal symbol period.

Figure 2 illustrates the detail block diagram of the Crest Factor reduction and amplitude pre-distortion circuit unit. The received signal from multi-carrier wireless transmitter 100 is applied to multi-carrier receiver 201 to produce signal 400. The output of the multi-carrier receiver 201 is applied to signal processing block 203 for digital signal processing which is Crest Factor reduction and amplitude pre-distortion and filtering of baseband representation of each carrier. The output of signal processing block 203 the Crest Factor reduced and amplitude pre-distort signal 402 is applied to multi-carrier transmitter 204 to create the input signal 102 for the multi-carrier amplifier. The received feedback signal 101 from the output of the amplifier is applied to envelop detection circuit 202 to produce the envelop signal 401. The envelop signal 401 and the main signal 400 are used by

digital signal processing block 203 to produce the amplitude pre-distortion look up table. Clock generator 206 produces all the clocks necessary for the Crest Factor reduction and amplitude pre-distortion circuit and the power supply block 205 produce all the voltages necessary for the Crest Factor reduction and amplitude pre-distortion circuit.

Figure 3 shows the detail block diagram of the Crest Factor reduction and amplitude pre-distortion signal processing block 203. The multi-carrier receiver block 201 output 400 is applied to analog to digital converter (in case the signal is RF, IF, or baseband) block 500 to produce the digital signal 410. If the signal is RF or IF the analog to digital conversion is based on sub-harmonic sampling. The output of the analog to digital converter 500 is applied to the DSP block 501 for down conversion and decimation to produce "m" sample per symbol. In case the signal is a multi-carrier baseband, the signal may need to be interpolated or decimated to produce the right number of samples per symbol. If the signal is baseband but in bit format then an up conversion function in 501 is used. The signal is first converted to symbol domain with desired samples per symbol and then each channel is up converted to its baseband frequency to produce multi-carrier baseband. The DSP block 501 also performs Crest Factor reduction and amplitude pre-distortion and produce signal 412. The Crest Factor reduced and amplitude pre-distort signal 412 is applied to up converter and interpolator 502 to produce the up converted and interpolated signal 413. Signal 413 is applied to digital to analog converter 503 to produce the analog signal 402 for the multi-carrier transmitter block 204.

Figure 4 shows the block diagram of the Crest Factor reduction and amplitude pre-distortion block 502. The multi-carrier baseband signal 410 from the main multi-carrier receiver 201 has its amplitude clipped by amplitude clipping block 510 to produce amplitude limited multi-carrier signal 420. The amplitude limited signal 420 is down converted to single carrier baseband signals by block 511 to produce the baseband representative of each individual carrier. The individual single carrier baseband signals 421 are filtered by filter block 512 to produce the filtered signals 422. The filtered signals 422 are applied to block 513 to reconstruct the multi-carrier baseband signal 423. The reconstructed multi-carrier signal 423 is amplitude pre-distorted by block 514 using

data from look up table 515 to produce Crest Factor reduced and amplitude pre-distorted signal 412.

Figure 5 shows the detail block diagram of the Crest Factor reduction circuit. The multi-carrier baseband signal 410 from the receiver is applied to amplitude clipping block 510 to produce amplitude limited multi-carrier signal 420. The amplitude limited signal 420 is applied to down converters 601, 602, and 603 to produce the baseband signal of each carrier 701, 711, and 721. The second input to down converters 601, 602, and 603 are supplied by NCOs 661, 662, and 663. The baseband representative of each carrier then is applied to Low Pass Filters (LPF) 611, 612, and 613 to filter unwanted signals. The filtered baseband representative of each carrier 702, 712, and 722 is applied to up converter blocks 651, 652, and 653. The other signal used by up converter is supplied by NCOs 681, 682, and 683. The up converted signals 706, 716, and 726 are then combined in block 600 to produced the new multi-carrier baseband signal 423. In figure 5 only a multi-carrier with 3 carrier is shown. This approach can be applied to unlimited number of carriers.

Figure 6 shows the detail block diagram of the lookup table adaptation algorithm. The multi-carrier Crest Factor reduced baseband signal 423 from the main multi-carrier receiver is gain adjusted by 320 and delay adjusted by 322 and then applied to look up table adaptation algorithm 323. The feedback multi-carrier digitized envelop signal 427 from the feedback envelop detector block 202 is gain adjusted 321 before being applied to lookup table adaptation algorithm323. The adaptation algorithm 323 uses the two signal to produce the update values 425 for the lookup table 515. The adaptation algorithm can use one of the existing prior art techniques.

Figure 7 shows the gain adjustment procedure in the path of the two inputs 423 and 427 to the lookup table adaptation algorithm block 323. Block 325 the gain adjustment algorithm gets its input from the output of the blocks 321 and 322. The automatic gain control operation with common set-point which is performed by block 325 adjust the gain in blocks 320 and 321, which allow the lookup table adaptation algorithm to operate on signals of known and common amplitude level. The dynamic range requirements of the

adaptation algorithm is therefore reduced. This automatic gain control operation is not performed upon the main multi-carrier input signal in the main signal path.

Figure 8 shows the detail of the correlator or comparator which can be used in both delay adjustment and gain adjustment algorithms. The signals 428 and 429 with reverse polarity are applied to the block 327 to be summed. The output of block 327 should be zero if both signals 428, and 429 are aligned in time and have the same amplitude. This concept is used in the gain adjustment algorithm. In the case of the gain adjustment algorithm during calibration an all 1s or all 0s digital sequence with known amplitude is used for signal 423 and send to the amplifier. Then the amplitude of the signal 423 and the envelop of the feedback signal from output of the amplifier 427 are gain adjusted in blocks 320 and 321 until the sum of signals 428 and 429 with reverse polarity in block 327 is zero. If the sum is not zero then for gain adjustment block 329 based on the output signal of the block 327 calculates the gain adjustment and send the gain adjustment values 450 and 451 to blocks 320 and 321. This process continues until the output of block 327 is zero. During the normal operation of the Crest Factor reduction and amplitude pre-distortion circuit the gain adjustment process continues using the actual signals.

Once the gain adjustment is completed, for phase adjustment a known digital pattern with high auto-correlation is sent to amplifier. The envelop of this kwon pattern signal 428 and the envelop of the feedback signal from output of the amplifier signal 429 with reverse polarity are applied to block 327 and summed. The output of block 327 then is applied to block 328 to calculated the amount of phase adjustment 452 that will be applied to phase adjustment block 322. This process will continue until the output of the block 327 converge to zero. During the normal operation of the Crest Factor reduction and amplitude pre-distortion circuit the phase adjustment process continues using the actual signals.

Figure 9 shows the detail block diagram of the delay adjustment algorithm. The algorithm operates in two modes. During the initial mode the initial delay between main signal from the main multi-carrier receiver 201 and the feedback signal from the feedback envelop

detector 202 is calculated. During this mode the signal 423 is replaced with a known sequence with very high auto-correlation. The signal input 427 will be decimated to m times the symbol rate, with a sampling phase resolution at minimum of 1/k times the symbol period by block 326. The sampling phase is repeatedly adjusted in increments of 1/k of the symbol period and correlated with known sequence 423 in block 324 to determine the delay present to a high degree of precision required by the lookup table adaptation algorithm in block 323. In operation, this delay will be compensated for by digitally delaying the signal from input 423 by an integer number of samples in block 322, and adjusting the sampling phase of the decimator in block 326 based upon the delay measurement results obtained in block 324 using the delay adjustment algorithm which is based on correlation of the output of blocks 322 and 321. In operation lookup table adaptation algorithm 323 then operates upon the output signal 100 from the wireless multi-carrier transmitter and the feedback envelop signal 101 from the amplifier output, which are precisely aligned in time and phase relative to each other. This adjustment is adaptively maintained during operation, to compensate for any delay variations caused by amplifier properties changing with aging effect and temperature variation.

Figure 10 shows the decimator block diagram of 326, which is used for delay adjustment of the two inputs into the lookup table adaptive algorithm. The decimator filter coefficients are changed based on the delay adjustment algorithm block 324 output 426 to produce phase change steps of T/k.